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NASA TECHNICAL TRANSLATION NASA TT F-14,859

SOLAR ELEMENTS BASED ON HETEROJUNCTION OF P-TYPE $GaAs_{1-x}P_x$ AND N-TYPE GaAs

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Translation of: "Solnechnyye elementy na osnove geteroperekhodov p-$GaAs_{1-x}P_x$ -n- GaAs", Geliotekhnika, No. 1, 1972, pp. 30-33.

(NASA-TT-F-14859) SOLAR ELEMENTS BASED ON HETEROJUNCTION OF P-TYPE GaAs(1-X)Px AND N-TYPE GaAs (Linguistic Systems, Inc., Cambridge, Mass.) 8 p 20 b

N73-20793

Unclas

G3/26 66670

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 APRIL 1973

9

STANDARD TITLE PAGE

1. Report No.
NASA TT F- 14,859

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
SOLAR ELEMENTS BASED ON HETEROJUNCTION OF P-TYPE $GaAs_{1-x}P_x$ AND N-TYPE GaAs

5. Report Date
April 1973

6. Performing Organization Code

7. Author(s)
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8. Performing Organization Report No.

9. Performing Organization Name and Address
LINGUISTIC SYSTEMS, INC.
116 AUSTIN STREET
CAMBRIDGE, MASSACHUSETTS 02139

10. Work Unit No.

11. Contract or Grant No.
NASW-2482

12. Sponsoring Agency Name and Address
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

13. Type of Report & Period Covered
TRANSLATION

14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: "Solnechnyye elementy na osnove geteroperekhodov p-$GaAs_{1-x}P_x$ -n- GaAs", Geliotekhnika, No. 1, 1972, pp. 30-33.

16. Abstract

Measured dark current-voltage characteristics, light current-voltage characteristics under load, and spectral response curves are given for photosensitive elements prepared by liquid epitaxial growth of p-type GaAs/1-x/P/x/ on an n-type GaAs substrate. Due to the absence of a conditioning surface layer, 30% of the radiation incident on the working surface is reflected, yielding an efficiency of 6 to 7%. Recommendations are given for improvement in this area.

17. Key Words (Selected by Author(s))

18. Distribution Statement
UNCLASSIFIED - UNLIMITED

19. Security Classif. (of this report)
UNCLASSIFIED

20. Security Classif. (of this page)
UNCLASSIFIED

21. No. of Pages
~~7~~ 9

22. Price
$3.00

NASA TT F-14,859

SOLAR ELEMENTS BASED ON HETEROJUNCTION OF P-TYPE $GaAs_{1-x}P_x$ AND N-TYPE GaAs

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The development of epitaxial methods of growing thin films of different semiconductor crystals made it possible to create heterostructures in the system $GaAs_{1-x}P_x$-GaAs, which is of interest because of the possibility of creating effective photoelectric converters having a number of significant advantages in comparison with silicon photoconverters [1-5]. /30

Solid solutions of $GaAs_{1-x}P_x$ make it possible to obtain the optimal width of the forbidden band, allowing the percentage of solar energy used to be increased. Photocells based on $GaAs_{1-x}P_x$-GaAs heterojunctions can operate at elevated temperatures and with light concentrators without significant changes in the energy parameters ($I_{k.e.}$, $U_{n.l.}$, efficiency).

The present article presents the results of investigations of the current-voltage, load and spectral characteristics of heterostructures, prepared by means of liquid epitaxial growth of solid solutions of $GaAs_{1-x}P_x$ on a GaAs substrate. The purpose of these investigations is to show the possibilities for using p-$GaAs_{1-x}P_x$—n-GaAs heterojunctions as photoconverters.

Single-crystal films of solid solutions of $GaAs_{1-x}P_x$ were obtained by epitaxial growth from the liquid phase on a gallium arsenide substrate [6-7]. N-type GaAs was used as the substrate material with μ = 2500-3500 cm^2 v·sec and an electron concentration of $7 \cdot 10^{16}$ to $4 \cdot 10^{17}$ cm^{-3} at room temperature. Oriented n-GaAs crystals in the plane (111) were covered with a gallium solution containing dissolved gallium phosphide and an alloying

*Numbers in righthand margin indicate pagination of foreign text.

admixture, zinc, in a pure hydrogen atmosphere. The process of growing single-crystal films of p-$GaAs_{1-x}P_x$ was conducted in the temperature range from 760 to 910° C. The temperature regime chosen for the growth process provided for coincidence of location of the heterojunction with the substrate-film boundary, and also made it possible to avoid the formation of a homojunction in the gallium arsenide as the result of zinc diffusion from the growing epitaxial film. The thickness of the epitaxial films was usually 20-30 μm.

The composition and homogeneity of the solid solutions were controlled radiographically and by measuring the reflection spectra [8]. The GaP content in the solid solutions was 10 molar percent; the concentration of charge carriers in p-film of $GaAs_{1-x}P_x$ approximately $2 \cdot 10^{18}$-10^{19} cm^{-3}. After chemical treatment ohmic contacts were applied by fusing indium in a hydrogen atmosphere.

The dark current-voltage characteristics of photocells are described by the equation $I = I_0[\exp(eU/\beta kT) - 1]$. The characteristic dependence $\ln I = f(U)$ in the forward direction in the voltage range $kT/e < U < U^I_{ots}$ for specimens obtained at a growing temperature of 830° C and different cooling rates are shown in Fig. 1. As is apparent from the figure, the dependence of $\ln I_{fd}$ on voltage for p-$GaAs_{1-x}P_x$—n-GaAs heterojunctions is characterized by one linear section, the inclination of which is $\beta = 1.8$ to 2.0 and $I_0 = 10^{-10}$ a/cm^2, satisfactorily agreeing with the theory [9], that is, an injection mechanism of current flow with a recombination of space charge carriers in the film is observed. The appearance of the dark current-voltage characteristics and the parameters β and I_0 depend on the mode of cooling the gallium solution, saturated with phosphorous and arsenic, and there is a certain optimal cooling regime, leading to a characteristic corresponding to the theory [9]. At higher bias voltages no /31

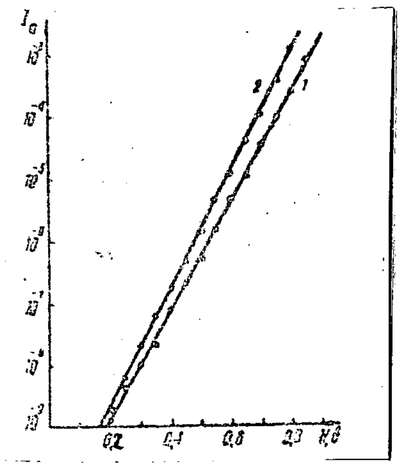

Fig. 1. Forward branch of the dark current-voltage characteristic of p-$GaAs_{1-x}P_x$—n-GaAs heterophoto cells at 300° K, obtained at different cooling rates. Cooling rate, °C/min: 1-10; 2-15.

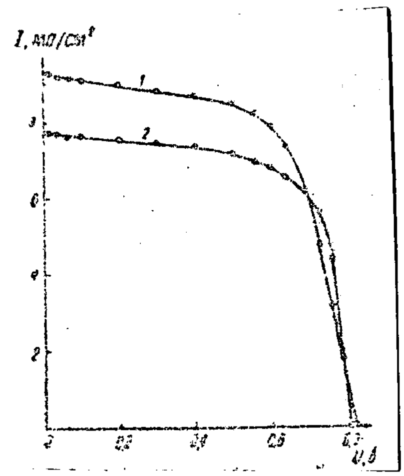

Fig. 2. Load characteristics of p-$GaAs_{1-x}P_x$—n-GaAs photocells (x = 0.1) with solar illumination. Cooling rate, °C/min: 1-10; 2-15.

section with a small β is observed in the forward direction, which may be connected with the greater series resistances of the instruments.

An increase in the cooling rate should lead to the preservation of a dissolved impurity in the persistant state, i.e., to smaller values of β and I_0. However, in this case there is an increase in the probability of the formation of structural defects introduced in the case of the epitaxial growth of heterojunctions on the substrate-film interface. Such factors significantly influence the appearance of the load characteristics of /32 p-$GaAs_{1-x}P_x$—n-GaAs solar cells in which the depth of the currents of the p-n-structure is from 1-4 μc and is on the same order of magnitude as the depth of penetration of surface defects. Fig. 2

shows the load characteristics, measured with a solar illumination with a power of 720 watts/m^2, of two p-$GaAs_{1-x}P_x$—n-GaAs solar cells, obtained at cooling rates of 10° C per min and 15° C/min. With a greater cooling rate the short circuit current decreases. Evidently, in the case of an abrupt cooling of a saturated gallium solution an increase in the concentration of defects is possible, which influences the parameters determining the magnitude of the photoelectric current, for example, the minority carrier lifetime.

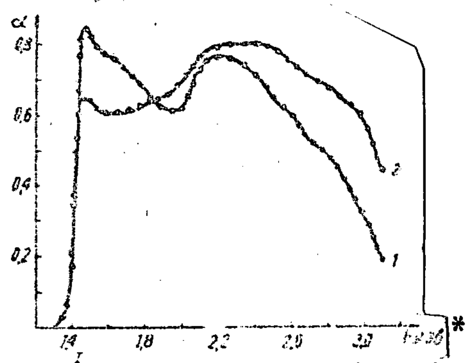

Fig. 3. Spectral distribution of the collecting coefficient at T = 300° K; cooling rate, °C/min: 1-10; 2-15.

On the other hand, on the heterojunction interface defects may arise as a result of a difference in the constants of the GaAs and the $GaAs_{1-x}P_x$ crystal lattices. Since the composition of the solid solutions are close to GaAs, then probably the difference in lattice constants plays a lesser role in the formation of recombination centers. At slower cooling rates there is a more uniform distribution of impurities in the p-layer grown and a decrease in the effective concentration of recombination centers, which leads to an increase in the minority carrier lifetime and, correspondingly, of the photocurrent lifetime.

The basic parameters of the photocells, determined from these characteristics, have the values: 1) no load voltage $U_{n.l.}$ = 0.81 to 0.83 v; 2) short circuit current $I_{s.c.}$ = 7.5 to 10 ma/cm^2; 3) efficiency η = 6-7%; 4) space factor γ = 0.6-0.7.

Analyzing the value of efficiency obtained, it is necessary to bear in mind that due to the absence of a transparent layer

*Illegible.

on the specimen around 30% of the radiation incidence upon it is reflected from the working surface of the cell. Therefore, after the application of a transparent coating and the completion of several technical processes the efficiency increases. The spectral distribution of the collecting coefficient of pairs of the junctions, recalculated for one incident photon with regard to the reflection coefficient in relation to the photon energy, is shown in Fig. 3. From Fig. 3 it is obvious that the region of photosensitivity of the heterophotocell is sufficiently wide and is limited by the energy range 1.4-3.2 ev. On spectral sensitivity curves two long-wave maxima are clearly pronounced with an energy of 1.15 ev close to the width of the forbidden band of GaAs and a wide short-wave maximum at an energy of 2.2-2.4 ev. The maximum of the collecting coefficient at 1.45 ev is caused by the absorption of light in the volume and the separation of photo-carriers on the heterojunction interface. Expansion of the spectral distribution of the collecting coefficient in the short-wave region of the spectrum and the increase in α (hv) depend, evidently, on the increase in the diffusion length of the electrons as a result of the presence of an electric drift field due to the variable width of the forbidden band of the p-region. However, determination of the composition of the film grown did not indicate a great /33 deviation from [...]* and was on the order of 10 molar percent GaP in the solid solution. On the other hand, excitation of excess carriers takes place in different parts of the Brillouin zone. This indicates that the minority excess carriers, excited in the different extremes of the conduction band, basically succeeds in going into equilibrium in the zone after a time less than the lifetime (less than 10^{-9} s). Probably, the wide maximum of heterojunction photosensitivity in the region 2.2-2.5 ev is caused by indirect transition in the X point of the conduction band [10]. The drop in photosensitivity in the energy region

*Illegible.

above 2.5 ev may be produced by the increase in the role of surface recombination with the increase in the coefficient of light absorption.

The basic work of the heterophotocells obtained is that solar cells based on them may be used for operation at high temperatures, above 200° C, and also that there is the possibility for increasing the percentage of usage of the energy of the solar spectrum. Further perfection of the technique of obtaining higher quality epitaxial films of solid solutions of $GaAs_{1-x}P_x$ and the creation of heterojunctions will allow for a significant increase in photocell efficiency.

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